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FLEXURAL RESISTANCE OF SELF COMPACTED CONCRETE BEAMS BY PARTIAL REPLACEMENT OF OPC WITH GGBS

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ABSTRACT

Self compacting concrete (SCC) has the property of flowing and compacting due to its own weight. Since compacting of concrete in the presence of grid locked reinforcements are increasing, the need for self flowing concrete is felt very much. Meanwhile Ground Granulated Blast Furnace slag (GGBS) will be an effective alternate to cement which contains cementitious material. In this study, self compacting concretes were considered using GGBS by replacing Portland cement with 10%, 20%, 30%, 40% and 50% by weight. The rheological and mechanical properties of SCG (GGBS incorporated SCC) were found to be increased compared to conventional concrete. Six reinforced concrete beams (SCGB) of shear span to depth ratio (a/d) 2 were tested for flexural capacity and ductile behaviour. The experimental cracking moment of SCGB beams were found to be more than the theoretical cracking moment enhancing its flexural resistance. Also, SCGB beams with higher percentage of GGBS exhibits higher ductility. The outcomes reveal that use of GGBS in SCC enables higher performance with economy and sustainability.

Key words: Self Compacting Concrete; GGBS; Rheological Property; Mechanical Property; Flexural Capacity; Ductile Behaviour.

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1. INTRODUCTION

Self compacting concrete (SCC) is defined as a concrete that exhibits a high deformability with good resistance to segregation [1]. The SCC is distinguished by its high fluidity, passing ability and cohesiveness characteristics that eliminate or reduce to a minimum the need for mechanical compaction [2] and has been widely employed to produce structural elements of complex shapes and/or with high density of reinforcement in structures [3]. Since the self-compacting concrete can reach self-leveling work performance in the fresh state by only relying on the action of gravity, there is no need of applying external vibrations in construction sites, which not only improve the quality of concrete placing, but also can greatly save time and labour needed in the construction sites [4]. Hence in the last 15 years, self-compacting concrete has been widely used around the world for its superior constructive ability and higher durability [5].

The production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [6]. The use of pozzolans as additives to cement, and more recently to concrete, is well accepted in practice to reduce the use of Portland cement. Ground granulated blast furnace slag (GGBS) is one such pozzolanic material identified by IS456:2000 as a supplementary cementitious material which can be used as a cementitious ingredient in either cement or concrete composites [7].

2. PAST RESEARCH

Ha Thanh Le et al [8] has found that increase in the fineness of rice husk ash content decreased the expansion of mortar due to alkali silica reaction in SCC containing rice husk ash and silica fume. Mohamed I Abukhashaba et al [1] has studied the environmental economic and technical benefits of self compacting fibre reinforced concrete containing cement kiln dust.

The mechanical strength and workability development with the use of cement kiln dust in SCC has been reported. Mostafa Jalal et al [9] presents the effect of silica nano particles, silica fume and class F fly ash as admixtures in high performance self compacting concrete. The use of fly ash improved the rheological property and the use of silica nano particles and silica fume improved the mechanical and transport properties of SCC.

Saifullah I et al [10] has performed experimental investigations on flexural behaviour of under reinforced concrete beams and compared it with analytical results. M K Maroliya [11] has performed a comparative study on flexural behaviour of prestressed concrete beams with reinforced concrete beams. Arivalagan S [12] has dealt with flexural behaviour of reinforced fly ash concrete beams. Oner A et al [13] has carried out experiments to determine the optimum usage of GGBS in concrete to increase the compressive strength. Sonali K Gadpalliwar et al [14] has partially replaced cement with GGBS and reported increase in workability.

In the history of researches related to SCC rise husk ash, silica fume, cement kiln dust, silica nano particles and fly ash were used as admixtures in SCC. The study of rheological, thermal and transport properties has only been reported. But in the current work, GGBS has been employed as a replacement to OPC and along with rheological and mechanical properties, the flexural behaviour of SCC beams were also accounted.

3. MATERIALS USED

3.1. Cement and Aggregates

53 grade Ordinary Portland cement conforming to IS 12269:1987 with specific gravity 3.15 was used. River sand obtained from Chennai and the locally available blue metal crushed stone aggregates of size 20mm were used as fine and coarse aggregates respectively. Their properties like specific gravity, bulk density, percentage of water absorption and fineness modulus were obtained as per IS 2386:1963 and shown in Table 1.

Table 1 Properties of Aggregates

Type	**Fine aggregate**	**Coarse aggregate**
Specific gravity	2.67	2.6
Fineness modulus	2.36	4.81
Water absorption (%)	0.5	1.21
Bulk density (kg/m^3)	1628	1562

3.2. Mineral Admixture

Ground Granulated Blast furnace Slag (GGBS), obtained from JSW Cement Limited, Chennai and conforming to IS 12089:1987 was used as the mineral admixture. The physical and chemical properties (as given by the manufacturer) of GGBS used for this study is given in Table 2.

Table 2 Properties of GGBS

Chemical properties		
Parameter	**JSW GGBS (%)**	**Codal provisions**
CaO	37.34	----
Al_2O_3	14.42	----
Fe_2O_3	1.11	----
SiO_2	37.73	----
MgO	8.71	Max. 17%
MnO	0.02	Max. 5.5%
Sulphide sulphur	0.39	Max. 2.0%
Loss on ignition	1.41	----
Insoluble residue	1.59	Max. 5.0%
Glass content (%)	92	Max. 85%
Physical properties		
Description		Value
Fineness of GGBS		13.1%
Specific gravity of GGBS		2.93

3.3. Water

Potable water with pH 7 and as available in SRM Campus was used.

3.4. Superplasticizer

Ceraplast 300 RS(G) which is sulphonated naphthalene formaldehyde condensates (SNF) type superplasticizer was used to increase the workability of self-compacting concrete at fresh state as reported by the manufacturer and given in Table 3.

Table 3 Properties of SNF type superplasticizer

Specific gravity (30˚C)	1.235
pH (10% solution)	8.5±0.5
Solid %	43±0.5
Sodium sulphate content	< 4%
Viscosity (30˚C)	20±6

MIX DESIGN

The design mix was prepared for M30 grade SCC as per ACI guidelines based on the effect of GGBS as binary blended cement [15]. Based on the strength obtained from trial mix given in Table 4, the actual mix was formulated. The mix type was established by the combination of powder type and Viscosity Modifying Admixture (VMA) type which is prepared by increasing powder content i.e. GGBS and using VMA i.e. superplasticizer. The concrete mix proportions of GGBS incorporated SCC here after designated as SCG were as shown in Table 5. The SCG mixes with 0%, 10%, 20%, 30%, 40% and 50% GGBS were termed as SCG0, SCG10, SCG20, SCG30, SCG40 and SCG50 respectively.

Figure 5 were found to decrease by 0.003%, 2.4%, 4.9%, 5.8%, 7.5% and 27.18%, 30.23%, 35.74%, 14.25%, 16.73% with the replacement of 10%, 20%, 30%, 40%, 50% GGBS to SCC respectively. Bouzoubaa et al [17] has reported that increase in percentage of fly ash decreases the slump flow, the same holds good for GGBS also as shown in Table 6 and Figure 2. It is clearly evident from Table 6 and Figure 3 that the time taken by the SCG mixes to flow through the V- funnel decreases by 1.7%, 0.01%, 1.7%, 0.01% with replacement of 10%, 20%, 30%, 40% GGBS and increases by 0.01% with replacement of 50% GGBS in SCC respectively which is not in good agreement with O.R. Kavitha et al [18] where metakaolin is used as mineral admixture without addition of VMA. This may be because of the nature of GGBS to enhance the rheological properties of SCC as specified by M.S.Shetty [19]. Also it is observed from Table 6 and Figure 4 that the blocking ratio was found to increase by 6.3%, 9.96%, 10.98% and decrease by 5%, 5.37% for SCG10, SCG20, SCG30 and SCG40, SCG50 respectively which is in accordance with Navid Ranjbar et al [20].

Table 4 Trial Mix

Designation of mix	Cementitious binder by weight		FA by weight	CA by weight	Water content by weight of cement	Percentage of SP by volume of concrete	Compressive strength at the age of 28 days (N/mm^2)
	OPC	GGBS					
Trial 1	1	0	1.51	1.78	0.35	6	28.64
Trial 2	1	0	1.51	1.78	0.35	4	30.56
Trial 3	1	0	1.51	1.78	0.35	2	36.81

Table 5 Validation of Mix design

Designation of mix	Cementitious binder by weight		FA by weight	CA by weight	Water content by weight of cement	Percentage of SP by volume of concrete
	OPC	GGBS				
SCG0	1	0	1.51	1.78	0.35	2
SCG10	0.9	0.1	1.51	1.78	0.35	2
SCG20	0.8	0.2	1.51	1.78	0.35	2
SCG30	0.7	0.3	1.51	1.78	0.35	2
SCG40	0.6	0.4	1.51	1.78	0.35	2
SCG50	0.5	0.5	1.51	1.78	0.35	2

4. RHEOLOGICAL PROPERTIES

The rheological properties of SCG mixes were found using slump test, V- funnel test, L - box test and U - box test as per EFNARC[16] recommendations and seen through Figure 1.

5. COMPRESSIVE STRENGTH

For getting compressive strength, 150 × 150 × 150 mm cubes were prepared using SCG mixes and tested in a universal testing machine of 2000 kN capacity at the age of 7, 28 and 56 days respectively. The reported strengths were the average of three specimens.

6. RESULTS AND DISCUSSION

6.1. Rheological property

The workability, filling ability and passing ability of SCC was measured by means of slump cone, V funnel and L-box and U-box respectively as shown in Figure 1 and Table 6. The slump diameter and the difference in height obtained from U-Box as shown in Table 6.

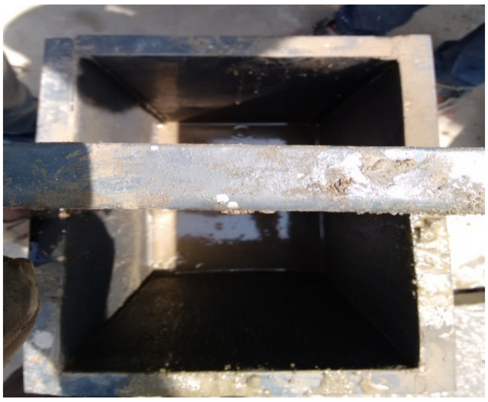
Table 6 Fresh Concrete properties

Mix	SCG0	SCG10	SCG20	SCG30	SCG40	SCG50	EFNARC values
Slump flow (mm)	708	706	691	673	667	655	650 - 800
V-funnel test (sec)	11.5	11.3	11.4	11.3	11.4	11.6	6 - 12
L-box (mm)	0.876	0.968	0.973	0.984	0.832	0.829	0.8 - 1
U-box (mm)	5.26	3.83	3.67	3.38	4.51	4.38	0 - 30

a)

b)

c)



d)

Figure 1. a) Slump flow test **b)** V- Funnel test **c)** L-Box test **d)** U- Box test

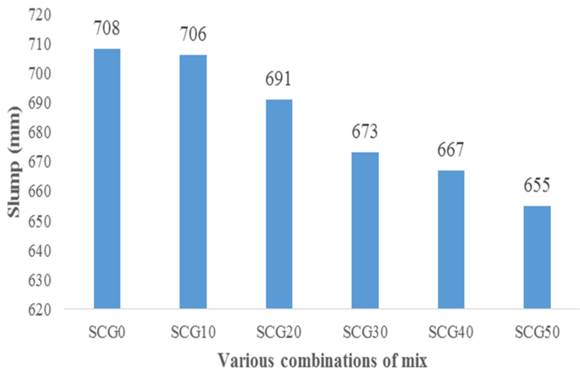


Figure 2 Slump flow of SCG mixes

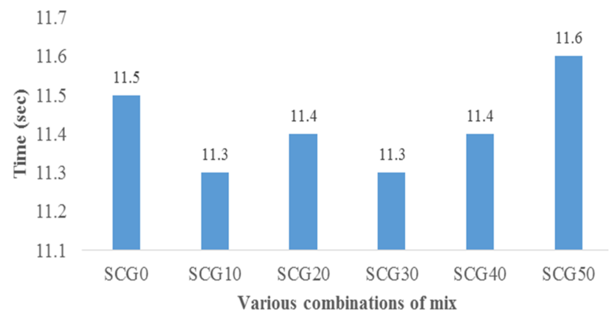


Figure 3 Filling ability of SCG mixes from V- funnel

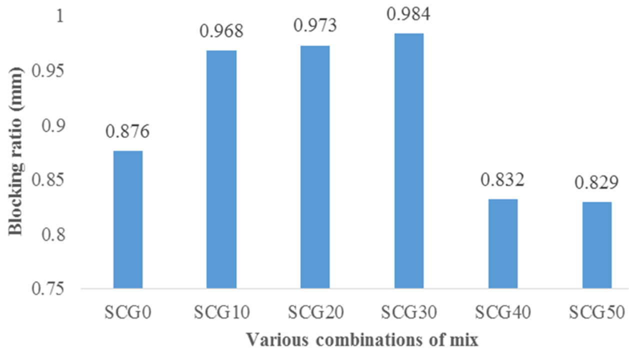


Figure 4. Passing ability of SCG mixes from L – box

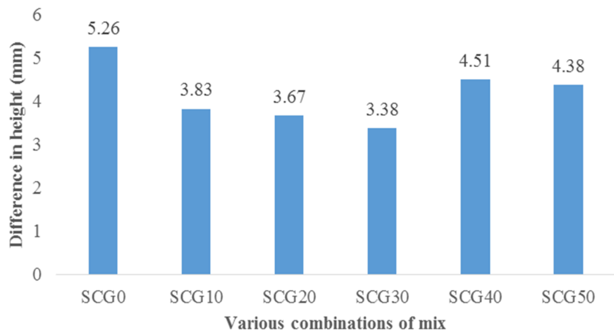


Figure 5 Passing ability of SCG mixes from U – box

6.2. Compressive strength

The mechanical strength of the SCC was determined by conducting compressive strength on SCG cubes at the age of 7, 28 and 56 days. At the age of 7 days, compressive strength of SCG10 and SCG20 were found to drop by 3.99% and 1.45% while compressive strength of SCG30, SCG40 and SCG50 were enhanced by 2.82%, 7.39% and 0.36% respectively from SCG0. It was noticed that the compressive strength of SCG10, SCG20, SCG30, SCG40, SCG50 were declined by 22.38%, 20.21%, 16.52%, 12.17% , 18.83% and improved by 2.69%, 3.16%, 4.55%, 7%, 5% at the age of 28 and 56 days respectively from SCG0. Watcharapong Wongkeo et al [21] suggested that compressive strength of SCC decreases with increase in percentage of fly ash but when GGBS was used in SCC, as shown in Table 7 and Figure 6 the increase in percentage of GGBS increases the compressive strength of SCG.

Table 7 Compressive strength of SCG beams

Sl.no	Specimen	Compressive strength (N/mm^2)		
		7th day	28th day	56th day
1	SCG0	27.55	36.81	39.85
2	SCG10	26.45	28.57	40.95
3	SCG20	27.15	29.37	41.15
4	SCG30	28.35	30.73	41.75
5	SCG40	29.75	32.33	42.85
6	SCG50	27.65	29.88	41.95

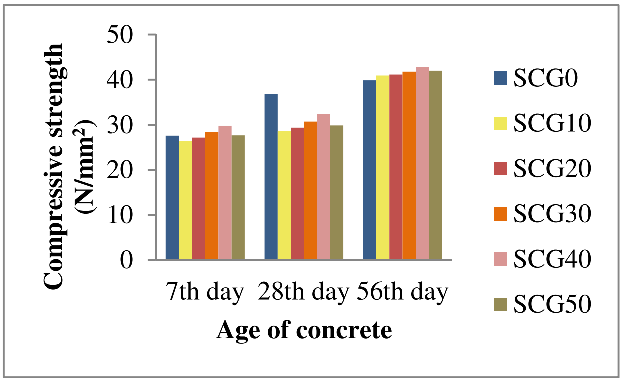


Figure 6 Compressive strength of SCG mixes

6.3. Flexural capacity of SCG beams

6.3.1. Beam Geometry

Six reinforced concrete prismatic beams with and without GGBS having 150 mm × 200 mm cross section with 1200 mm length designed as per IS456 were cast and tested. The shear span to depth (a/d) ratio of the beams were 2. All the beams were reinforced with two numbers of 12 mm diameter rods as main bars and two numbers of 10 mm diameter bars as hanger bars. The transverse reinforcements were provided with 2 legged 8 mm diameter rods at 115 mm center to center. The reinforcement cage and its outline is shown in Figure 7 and Figure 8 respectively. The beams were designed to fail in flexure.

Figure 7 Reinforcement cage

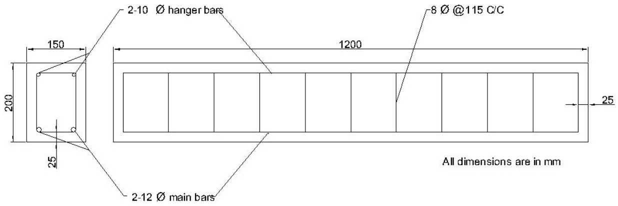


Figure 8 Beam reinforcement outline

6.3.2. Test procedure

All the specimens were white washed in order to facilitate marking of cracks. The sketch showing the details of the beam setup for the flexural test is shown in Figure 9. Testing was carried out on a loading frame of 40 tonnes capacity. Before resting the beam on reaction blocks, the beam was centered by using a plumb bob so that its centre lies exactly under the centre of the loading head. The beam was supported on the reaction blocks by a hinged plate at one end and roller plate at the other end to satisfy simply supported end conditions. The beams were tested under two point static loading with a constant moment region. The beams were simply supported over an effective span of 1000 mm between the supports. The experimental set up of SCGB beam is shown in Figure 10. The load was applied on two points, at a distance of 425 mm for a/d ratio 2 at centre to center of the load spreader. A dial gauge was placed at the center of the beam and the deflection readings were noted manually at every load increments.

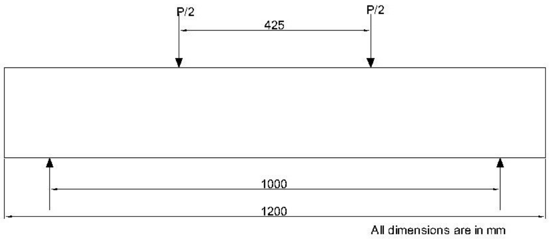


Figure 9 Test setup sketch

Figure 10 Experimental test set up

6.3.3. Crack pattern and failure mode of control beam

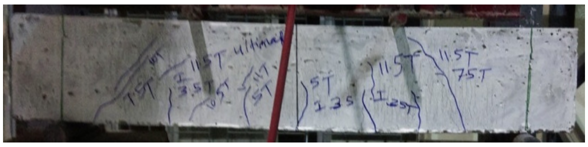
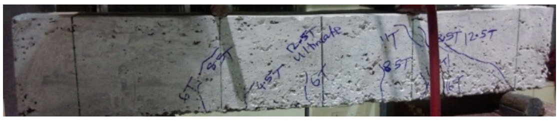


Figure 11 Crack pattern of control beam

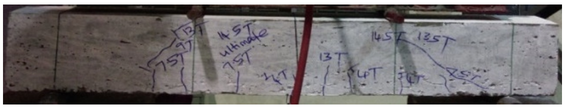
The initial crack and the final crack in the control beam specimen were noticed at the loading of 3T and 11.5T respectively. The control beam failed by developing diagonal crack in the shear region which extended up to the middle fibre as seen in Figure 11.

6.3.4. Crack pattern and failure mode of SCG beams

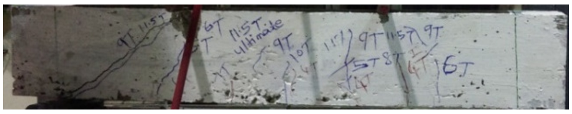
(a)



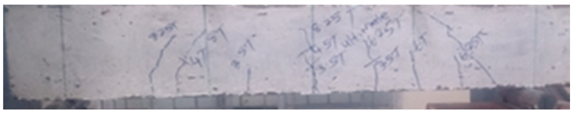
(b)



(c)



(d)



(e)

Figure 12 Crack pattern of SCG beams

The beams with 10%, 20%, 30%, 40% and 50% GGBS was observed to start yielding at 4T, 3.5T, 4T, 3.75T and 3.5T as reported from Table 8 and Figure 13. The initial crack load of beams with 10%, 20%, 30%, 40% and 50% GGBS was found to be 25%, 14%, 25% ,20% and 14% more than the initial crack load of the control beams respectively. The final crack for beams with 10% and 20% GGBS was found to be at 12.5T. Also the final crack for 30%, 40% and 50% occurred at 14.5T, 11.5T and 11T respectively. It was observed that the failure of beams was due to development of cracks in the lowermost tensile fibre which propagated towards the compressive fibres in beams with 10% GGBS as shown in Figure 12 (a) while the failure of beams was due to diagonal crack developed in the shear region propagated till middle fibre in beams with 20%, 30% and 40% GGBS as shown in Figure 12 (b), 12 (c) and 12 (d) respectively. Also it was observed that the diagonal cracks originated near the support extended till the compression zone in the flexural region of the beam for the beams with 50% GGBS as noted from Figure 12 (e).

Table 8 Initial and Final crack load of SCG beams

Beam ID	Initial crack load (T)	Final crack load (T)
CC	3	11.5
SCGB10	4	12
SCGB20	3.5	12.5
SCGB30	4	14.5
SCGB40	3.75	11.5
SCGB50	3.5	11

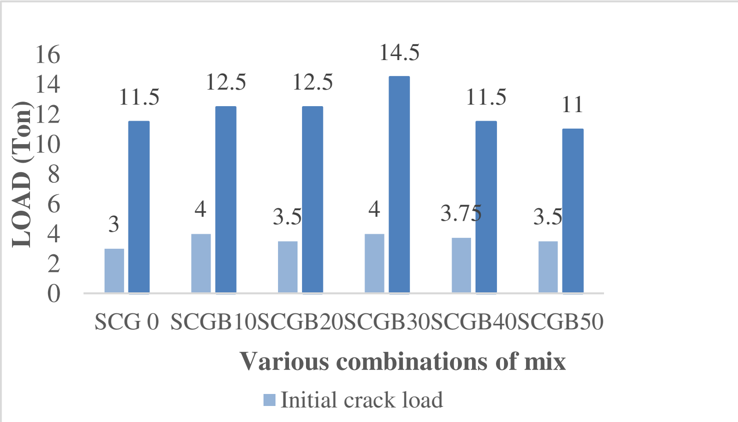


Figure 13. Initial and final crack load of SCG beams

6.3.5 Load deflection curve

The deflection values was noticed from the dial gauge placed at the centre of the beam by visual observation. In reinforced concrete structures it is of supreme significance that it should undergo large deformations before failure which is observed in SCG beams and found to be compatible with Delsye C.L.Teo et al [22]. It is clearly witnessed from Figure 14 that this criteria is achieved with replacement of GGBS to SCC. The SCG beams with higher GGBS content exhibited large deflections at lower loads resulting in a highly ductile failure. S.P. Sangeetha et al [23] recommended increase in load carrying capacity with addition of GGBS to concrete which is on par with SCC also.

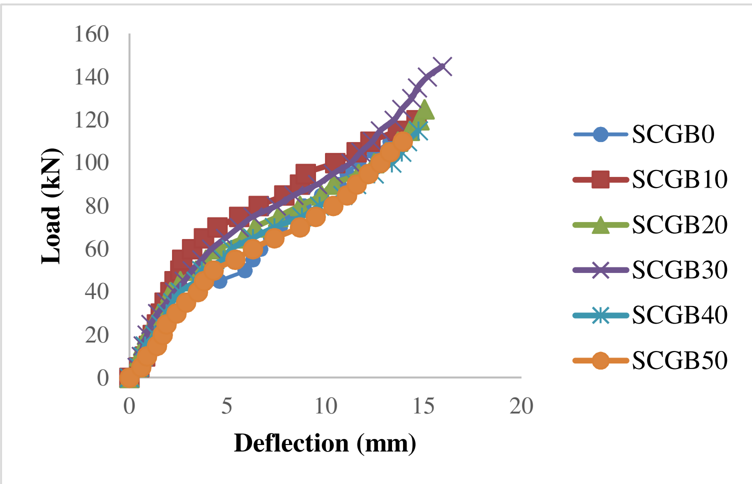


Figure 14 Load deflection curve of SCG beams

6.3.6. Moment carrying capacity

The theoretical cracking moment of the SCGB beams were determined through theoretical analysis adopting the transformed section method with the formulae stated in codes of practice IS456:2000 for plain and reinforced concrete as given in (1),

$$M_{cr(theoretical)} = \frac{f_{cr} \cdot I_{gr}}{y_t} \text{ [24] } - \quad (1)$$

where, f_{cr} is the modulus of rupture of concrete, I_{gr} is the moment of inertia of the gross section about the centroidal axis, neglecting the reinforcement and y_t is the distance from centroidal axis of gross section, neglecting the reinforcement, to extreme fibre in tension.

The experimental cracking moment $M_{cr(experimental)}$ was calculated from the product of shear span (a) and the one component of two point load (P). It is mathematically given in (2),

$$M_{cr(experimental)} = \frac{P}{2} \times a \quad (2)$$

Table 9 Theoretical and Experimental cracking moment

Specimen	M_{cr} (theoretical) (kNm)	M_{cr} (experimental) (kNm)
SCGB0	3.93	8.63
SCGB10	4.00	11.50
SCGB20	4.02	10.06
SCGB30	4.05	11.50
SCGB40	4.12	10.78
SCGB50	4.06	10.06

It is seen from Table 9 and Figure 15 that the experimental cracking moment of SCGB0, SCGB10, SCGB20, SCGB30, SCGB40 and SCGB50 is 54.46%, 65.21%, 60%, 64.78%, 61.78% and 59.64% more than the theoretical cracking moment. The experimental cracking moment were found to be tantamount to theoretical cracking moment which is similar to Dattatreya J K et al [25] who has used ACI 318 for determining theoretical cracking moment. This exposits that the replacement of GGBS to OPC in SCC develops the flexural behaviour of self compacting concrete beams.

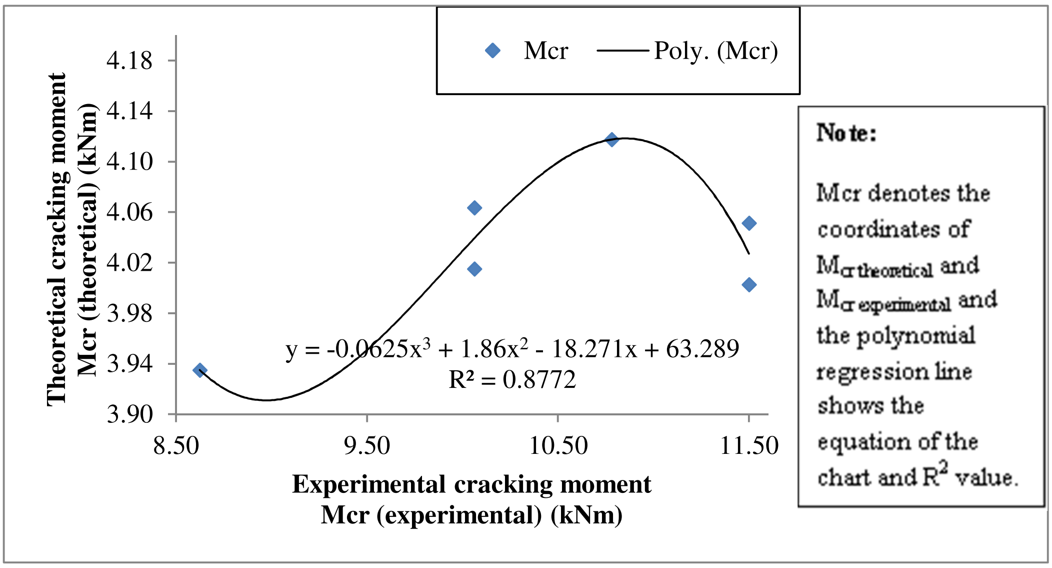


Figure 15 Cracking moment comparison

The R-squared value equals 0.8772, which is a good fit. Since it is closer to 1, it can be concluded that the experimental cracking moment is in accordance with theoretical cracking moment.

6.3.7 Ductility factor

The ductility behaviour of SCGB beams were analyzed theoretically using ductility factor (μ) which is the ratio of ultimate deflection (δu) to yield deflection (δy) as given in (3). Ultimate deflection is the deflection corresponding to the ultimate load and yield deflection is the deflection caused by the member during yielding. It is a dimensionless quantity given by the formulae,

$$\mu = \frac{\delta u}{\delta y} - \qquad (3)$$

Table 10 Ductility factor of SCG beams

Sl.no	Beam specimen	Ultimate deflection (δu)	Yield deflection (δy)	Ductility factor μ = δu/δy
1	SCGB0	13.7	4.3	3.19
2	SCGB10	14.6	3.7	3.94
3	SCGB20	15.2	3.8	4
4	SCGB30	15.9	4.1	3.88
5	SCGB40	14.8	4.7	3.15
6	SCGB50	13.9	4.5	3.08

It is observed from Table 9 that ductility factor of SCGB10, SCGB20, SCGB30 were 19%, 20.2%, 17.78% higher than conventional concrete where as SCGB40 and SCGB50 were 1.25% and 3.45% lesser than conventional concrete. This is similar to the work carried out by J. M. Srishaila et al [26] in which increase in GGBS content decreased the ductility factor, this may be because of its hard nature. Also it is contradictory to Magda I Mousa [27] where in ductility factor decreased with addition of silica fume in high strength concrete beams.

7. CONCLUSION

- The use of GGBS as partial replacement for OPC in SCC not only reduces the emission of CO_2 from OPC but also enhances the mechanical and rheological properties of SCC.
- The workability of SCC found by slump decreases with increase in percentage of GGBS, the time of flow through the V- funnel test time decreased with addition of GGBS in SCC and the blocking ratio obtained from L- box was found to be satisfactory up to 30% replacement of OPC with GGBS in SCC.
- At the age of 7 days, the compressive strength of SCG10 and SCG20 were found to drop by 5.58% and 18.91% while compressive strength of SCG30, SCG40 and SCG50 were enhanced by 4.02%, 10.17% and 0.01% respectively from conventional mix.
- It was noticed that the compressive strength of SCG10, SCG20, SCG30, SCG40, SCG50 were reduced by 28.85%, 26.05%, 21.29%, 15.68% , 24.26% and improved by 3.39%, 3.89%, 5.67%, 8.79%, 6.25% at the age of 28 and 56 days respectively from conventional mix.
- SCGB beams with higher percentage of GGBS exhibits higher ductility.
- The experimental cracking moment of SCGB0, SCGB10, SCGB20, SCGB30, SCGB40 and SCGB50 is 54.46%, 65.21%, 60%, 64.78%, 61.78% and 59.64% more than the theoretical cracking moment. This exposits that the replacement of GGBS to OPC in SCC enhances the flexural behaviour of self compacting concrete beams.

- Ductility factor of SCGB10, SCGB20, SCGB30 were 19%, 20.2%, 17.78% higher than conventional concrete where as SCGB40 and SCGB50 were 1.25% and 3.45% lesser than conventional concrete mix. Hence, it can be concluded that upto 30% replacement of GGBS to OPC in SCC is effective.

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